Journal of Integrative Agriculture 2016, 15(10): 2417–2425

Available online at www.sciencedirect.com

ScienceDirect

ELSEVIER

RESEARCH ARTICLE

Linking a farmer crop selection model (FCS) with an agronomic model (EPIC) to simulate cropping pattern in Northeast China

HE Ying-bin[1, 2], **CAI Wei-min**[2]

[1] *Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, P.R.China*
[2] *Management School, Tianjin Polytechnic University, Tianjin 300387, P.R.China*

Abstract

In this paper, authors established a farmer crop selection model (FCS) for the three provinces of Liaoning, Jilin and Heilongjiang of the Northeast China. With linking to the environmental policy integrated climate model (EPIC), the simulated results of FCS model for maize, rice and soybean were spatialized with 1 km×1 km grids to obtain cropping pattern. The reference map of spatial distribution for the three staple crops acquired by remote sensing imageries was applied to validate the simulated cropping pattern. The results showed that (1) the total simulation accuracy for the study area was 78.62%, which proved simulation method was applicable and feasible; (2) simulation accuracy for Jilin Province was the highest among the three provinces with a rate of 82.45% since its simple cropping system and not complex topography; (3) simulation accuracy for maize was the best among the three staple crops with a ratio of 81.14% because the study area is very suitable for maize growth. We hope this study could provide the reference for cropping pattern forecasting and decision-making.

Keywords: cropping pattern, staple crops, EPIC model, FCS model, simulation

1. Introduction

Because changes in land use and land cover are important signs of alterations to the earth's surface as a result of human activities, such changes have become a focus of geoscience research since the 1990s (Turner II *et al*. 1995; Lambin *et al*. 1999; IGBP 2001). Agriculture is a productive activity that is most closely related to land use by humans, and agricultural land use reflects pattern and extent of human impact on natural ecosystems at a landscape scale (Tang *et al*. 2004). The spatial pattern of crops in farmland ecosystems includes composition, spatial distribution of crops, multiple cropping or fallow cultivation, and rotation systems (Liu and Deng 2010); this pattern provides a spatial representation of human utilization of agricultural production resources and forms the basis for simulation studies on changes in the spatial structure of crops and potential adjustments and optimization of crop structures (Yin *et al*. 2006; Frondoni *et al*. 2011). Thus, it is very important to conduct research on simulation of spatial pattern and its changes.

Simulations of spatial pattern of crops must address the "human-environment relationship". In the geosciences, the current research methods to determine this relationship can be divided into two categories: top-down methods and bottom-up methods (Parker *et al*. 2003; Verburg 2006). The top-down methodology focuses on spatial statistical units of

Received 26 October, 2015 Accepted 13 November, 2015
HE Ying-bin, Tel: +86-10-82106225, E-mail: heyingbin@caas.cn; Correspondence CAI Wei-min, Tel/Fax: +86-22-83956271, E-mail: 2771215@sina.com

doi: 10.1016/S2095-3119(15)61247-3

land area or plot from a farmland-environmental perspective. The benefits of this methodology are easy to collect data, quantify influential factors and predict future changes in the parameters by employing time series methods (Tang *et al*. 2009). The models used in this methodology include the International Institute for applied systems analysis land use change (IIASA-LUC) (Fischer and Sun 2001), system dynamics model (Saeed *et al*. 2002), spatial statistical model for the conversion of land use and its effects (CLUE) (Verburg *et al*. 2004), logistic model (Xie and Li 2008) and conversion of land use and its effects at small regional extent (CLUE-S) model (Wu *et al*. 2012). However, these methods are unable to consider the impact of farmers' choices or decisions related to the farmland; thus, linking the spatial statistical units and decision-makers is difficult (Grimm *et al*. 2005).

Consequently, researchers have conducted simulations from the perspective of "farmer" (or agent) using a bottom-up methodology. This methodology applies agent-based models to investigate farmers' behavior in choosing crops and making judgments in terms of the maximum benefits of the crops harvest (Verburg and Overmars 2009). The models used include southern yucatán peninsular region integrated assessment (SYPRIA) (Manson 2005), people and landscape model (PALM) (Matthews 2006), the companion modelling approach (ComMod) (Barnaud *et al*. 2008), etc. This methodology has also been applied in simulation studies of the spatial patterning of crops in China using models, for instance, the land use change-artificial society model (LUC-ASM) (Huang *et al*. 2010). Chen H *et al*. (2010) applied multi-agent system (MAS) to study farmers' decision making and Yu *et al*. (2013) set up a CroPaDy model at village and town level to predict spatial patterns of crops. However, agent-based simulations of crop spatial patterns in China still remain several problems: (1) the agent-based method originated from Europe and USA. One of the required conditions for application is that the subjects being large farm that have easily defined boundaries, abundant contiguous crop acreage, and crops that can be confirmed (through inquiries with the farmer). However, crop production in China is mainly performed by farmers who work on small farms or in intertwined fields that belong to different farmers; thus, the farmland boundaries are difficult to define. Therefore, agent-based model studies have been mostly limited to the village or town level and would have additional limitations at even larger spatial scales. (2) Current studies have clustered individual farmers to analyze their crop selection decisions. However, researches have seldom been conducted from a perspective of entirety and generality provided by a collection of individual farmers. In addition, the decision-making of farmers was guessed by the researchers using general and common knowledge and thus, most of the basic decision-making processes of real farmers were frequently overlooked. (3) The spatially explicit of decision-making results, in other words, spatialization of the simulated results of cropping pattern after farmers' decision-making is still needed to be resolved. Based on the above-mentioned issues, this study aims to achieve the following objectives: (1) to establish a model, farmer crop model (FCS), directly from the overall perspectives of all the farmers in the study area, and by depicting real farmer decision-making process; (2) increase the spatial scale to a regional level that includes three northeastern provinces (Jilin, Liaoning and Heilongjiang) to overcome the spatial scale limitations found in previous studies; (3) introduce the EPIC model into the study to link with FCS model to better spatialize the simulated results of cropping pattern.

2. Materials and methods

2.1. Study area

The study area included three northeastern provinces in China: Liaoning, Jilin and Heilongjiang. These provinces are located at latitudes from 38°43´ to 53°33´N and longitudes from 118°53´ to 135°05´E, and they have a total area of approximately 7.9×10^5 km^2 (Fig. 1-A). The area has a typical continental temperate monsoon climate and a terrain that mainly consists of plains, hills and mountains, with agricultural land mainly located in the plains. There is a total of approximately 2.22×10^5 km^2 arable land, which occupies 16.8% of national total arable land (Chen Y *et al*. 2010). Most of the cultivated land in the region is located in the plains, and a relatively simple single cropping system for crops has been adopted (Li *et al*. 1994). Maize, rice and soybean have been listed as the three staple crops in the Northeast China, which account for approximately 90% of arable land and are usually planted contiguously in a large area (Chen Y *et al*. 2010). The Northeast China is a very important commercialized food production base and plays a great role for ensuring food security for entire country. Thus, it is extremely significant to implement relevant study in the targeted region.

2.2. Methods

Farmer investigation The purpose of the study was to establish a model simulating farmers' decision for selecting one of the three staple crops to grow at a regional spatial scale. Interviews with farmers were conducted in the study area to collect information on the factors that most directly affect the farmers' decisions. Actually, the work of farmer investigation started from the year 2003 when authors implemented a project "China Regional Arable Land Resources Changes

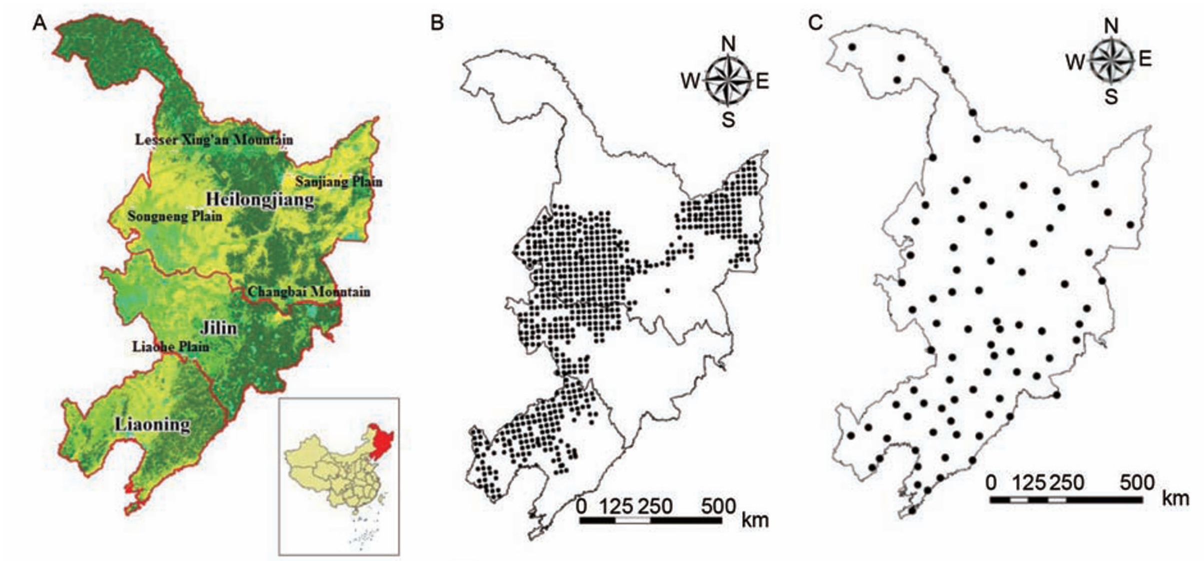

Fig. 1 Maps of the study area, climatic stations and soil sample locations. A, map of the study area. B, location of the soil sample extractions. C, location of the weather stations.

and its Early Warning — A Case Study in Northeast China" approved by Ministry of Science and Technology of China (project no.: 2004DIB3J092). Authors designed farmer investigation form including investigation items, such as farmer name, crop classification, crop phenological dates, field management data, education level, age, acreage of cropland farmer owns or rents, all kinds of costs and benefits for growing one kind of crop, preference for growing a kind of crop for farmer, and etc. When conducting investigation, authors attempted to balance the three crops and their spatial distributions, and the amount of the different farmer groups with different ages, living standard level. Great effort, during investigation, were also made to spatially-evenly cover arable land in the study area so as to fully consider geographical differences. Farmer investigation work were sometime conducted simultaneously with soil sampling (Fig. 1-B), but not limited to soil sampling spots. During implementing the project (project no.: 2004DIB3J092), a total number of 151 farmer household investigation were collected. Moreover, for achieving the objective of this paper, funded by the National Natural Science Foundation of China (41001049), we supplemented 57 farmer household investigation. After collection and collation, 208 qualified farmer investigation copies (75 copies for Heilongjiang Province, 69 copies for Jilin Province, and 64 copies for Liaoning Province) were applied in this study.

Based on summary and analysis from these farmer investigation forms, we could make beneficial conclusion for establishing the FCS model: (1) we could assume that farmers, who are not used to be classified, are all rational decision makers who choose crops to optimize their own interest. It, to great extent, facilitated to pave the way for simulation of spatial patterns of staple crops in Northeast China. (2) To build farmer crop selection models, factors such as the level of economic development of the region, lifestyle, cultural background, perspectives, habits and education level of the local farmers, consistency and uniformity of agricultural production, and shared personal preferences among the individual farmers must be considered. Fortunately, the three northeastern provinces have always been and will be considered as a whole because the farmers in the region share the same dialect, cultural background, perspectives, habits, and economic level, which provides a good foundation for the construction of a farmer crop selection model. (3) Influence of other cash crops on the simulation results was small. Such a situation rarely occurs in other areas in China. In addition, basic farmland protection policies that have been implemented in China helped prevent the occupation of the three staple crops lands by other types of land use and greatly reduced the complexity created by changes of land use. (4) The varieties of maize, rice and soybean planted in the region are rather small; thus, they share similar physiological and phenological features, making it possible to use a unified set of growth parameters for the EPIC model and allowing us to determine a spatially explicit pattern of staple crops in the region.

FCS model framework The FCS model was then constructed, and it was used to simulate the results of crop selection by farmers. The basic principle of the model is based on a perspective that includes all farmer households as a whole, with consideration of farmers, as rational decision makers, seeking to maximize benefits (this was consistent with the actual situation in the Northeast China determined in the interviews with the farmers). The net profit per unit area of a crop (1 km^2 in this paper) was calculated in terms of the gross revenue and cost factors. By comparing the net profits of the three crops (maize, rice, soybean), the crop that yielded the largest net profit was selected as the choice crop to plant for the farmers. The farmers' selection behavior was based on factors that influenced the farmers' decision-making process.

The year of study was 2009. At this time, the investigation was initiated to determine the farmers' crop selections to depict the spatial pattern of staple crops in the three north-eastern provinces in China. Data on natural-socio-economic factors, including factors related to the individual farmers, had a significant influence on the farmers' decision-making process; thus, such data were required to construct the model:

$$Profit_i=Yield_i\times Price_i+Profit_{worki}Coefficient_{worki}-Cost_{irrigationi}\times Coefficient_{irrigationi}-Cost_{fertilizeri}-Cost_{Seedi}-Cost_{pesticidei}-Cost_{hirei}-Coefficient_{ricei}-Coefficient_{slopei} \quad (1)$$

$$Crop=\max\ (Profit_i) \quad (2)$$

Where, $Profit_i$ is the net profit per unit area of crop i, with i representing either maize, rice or soybean (CNY km^{-2}); $Yield_i$ is the yield of crop i simulated by the EPIC model (kg km^{-2}); $Price_i$ is the purchasing price of crop i (CNY kg^{-1}); $Profit_{worki}$ is the income earned by farmers unrelated to farming, which occurred during the growth of crop i when the farmers had leisure time related to the relatively simple field management (farmers tending maize and soybeans in the study area were idle during the crop growth periods, so they migrated to urban areas to seek temporary jobs to earn extra revenue and returned for the harvest of the crops in the fall) (CNY km^{-2}); $Coefficient_{worki}$ is the adjustment coefficient of the income of the temporary job, which is assigned a value of 1 when maize or soybean was planted because the farmers could work during the crop growing season and a value of 0.5 when rice is planted because rice farming demands more field management and it is a little bit hard to take on temporary jobs during the crop growing season; $Cost_{irrigationi}$ is the cost of irrigation for the unit area of crop i (CNY km^{-2}); $Coefficient_{irrigationi}$ is the coefficient of irrigation cost, which is assigned a value of 1 for rice and a value of 0.5 for maize or soybean since the water supply for these two crops is partly independent on precipitation; $Cost_{fertilizeri}$, $Cost_{Seedi}$, $Cost_{pesticidei}$, and $Cost_{hirei}$ are the costs of fertilizers, pesticides, seeds, and employment, respectively, per unit area of crop i (CNY km^{-2}). In addition, two adjustment coefficients are innovated: $Coefficient_{ricei}$ accounts for the distance from the irrigation water source and $Coefficient_{slopei}$ accounts for the terrain slope for arable land. In practice, only rice can be planted in the river valley, which is 2 km wide buffer areas along the river, since the low-lying areas are often water-logged, which are not able to grow any crops other than rice; thus, when rice is planted, $Coefficient_{ricei}$ is set as 0, and when maize or soybean is planted, $Coefficient_{ricei}$ is set as 100 000 to ensure that the area is exclusively planted with rice. Actually the maximum gross profit for a farmer household was approximately 100 000 CNY in terms of farmer investigation. The explanation we set this number was that though gross profit of a farmer household reached peak of 100 000 CNY, the net profit should be at least 0, in other word, no gains when growing maize and soybean in the buffer areas of valley. Similarly, $Coefficient_{slopei}$ is set to ensure that arable land with a slope greater than 10° is planted exclusively with maize or soybean, so it is set to 200 000 when rice is planted. An extreme case occurs in which the slope of the terrain of the arable areas are larger than 10°, also inside the 2 km river valley zone. If so, there is a potential for maize or soybean cultivation; in this situation, the $Coefficient_{slopei}$ is set to 200 000 to ensure that maize or soybean is planted in the area. Finally, the parameter *Crop* is the last staple crop selected by the farmers, and it is determined by a comparison of the benefits of the crops calculated from eq. (2).

Spatialization of the FCS simulation results To spatialize the simulation result of the FCS model, the EPIC agronomic model was introduced in this study. The EPIC plant growth model was originally developed to estimate soil productivity as affected by erosion (Williams *et al*. 1984). Later, EPIC model showed its advantage in the aspect of simulating all crops with one crop growth model using unique parameter values for each crop (Niu *et al*. 2009; Van Der Velde *et al*. 2010). The EPIC model has been widely used around the globe (Williams and Arnold 2006). Also, it has been proved to be effective and efficient in the study area of the Northeast China, which greatly facilitated the research in this paper (Wang *et al*. 2008; Chavas *et al*. 2009). Because the model requires daily climatic data over the entire crop growth period, it provides an accurate reflection of the effect of climate on crop growth (Bryant *et al*. 1992). In addition, the inclusion of soil and field management data increases the accuracy of yield predictions (Cabelguenne *et al*. 1999). Most importantly, the model could spatialize yield and indirect results, which solves the problem of spatially explicit during simulation (Priya and Shibasaki 2001; Wu *et al*. 2007; Liu *et al*. 2009). Staple crops production areas originated from validation map derived from remote sensing imageries (Fig. 2-B). We gridded the staple crops production areas in the study area with a raster of 1 km×1 km, which was viewed as a spatial unit in the yield simulation using the EPIC model. We set one crop in the staple crops production areas to simulate yield of this crop, and then to simulated the other two crops. This meant to simulate one crop by one crop for the whole study area separately. The yield per unit area was used to be input to calculate $Profit_i$ and to determine *Crop* from eqs. (1) and (2). Eventually, simulation results for the spatial pattern of crops was obtained.

Validation of the simulation results of crops spatial pattern The reference map used to validate the result was the actual spatial distribution image of the rice, maize and soybean crops in the Northeast China that was acquired by the moderate-resolution imaging spectroradiometer (MODIS) in 2009. After corrections and adjustments, the precision of the map exceeded 90% (Huang *et al*. 2010, 2013). The spatial reference resolution of the map originally was 0.25 km×0.25 km. In order to verify and overlay the map with our results, we resampled it to a 1 km×1 km reference map. The ratio of the number of matching grids (on the simulated map after a comparison with the reference map) over the number of total grids was used as the indicator of accuracy in the range of 0-1, with 1 as the most accurate simulation and 0 as the least accurate.

2.3. Data collection and processing

The climatic factors required by the EPIC model included daily maximum temperature, daily minimum temperature, solar radiation, daily precipitation, daily relative humidity, and daily wind velocity. The data for the climatic factors of the three northeastern provinces were collected by 83 local meteorological stations of the State Meteorological Administration of China. And the daily data were averaged values for the period 1979–2008 for each meteorological station. The climatic data were then interpolated (Fig. 1-C) to fit the aforementioned 1 km×1 km grids and matched to the grids in the geographical space, while topography was considered in the process of data interpolation. The vector-based soil-type map (scale 1:1 000 000, from the Institute of Soil Science of Chinese Academy of Sciences, Nanjing) was similarly interpolated to the grid map and matched to the gridded climatic maps. In addition, crop type, cropping system, topography, irrigation conditions, and field management parameters were also recorded during famer household investigation. These information provided field management parameters for the EPIC model. The data for climate, soil and field management were input to the EPIC model to generate the spatial maps of yields per unit area of rice, maize and soybean.

The prices of fertilizer and pesticide and income from farmers' migrant work were collected from the questionnaire interview with farmers. The purchasing price of agricultural products was obtained from the *China Statistical Yearbooks* (National Bureau of Statistics of the People's Republic of China 1991–2010). The digital elevation model (DEM) data for the Northeast China (scale 1: 250 000) and vector map of hydrological systems were obtained from the Natural Resource Database of the Northeast China, which was previously created by the authors when implementing above-mentioned project of Ministry of Science and Technology of China. The data for the slope and buffer were derived from the DEM using ArcGIS (Esri, Redlands, CA, USA), and the spatial resolution was 1 km×1 km matching above-mentioned maps.

3. Results

3.1. Simulated cropping pattern of the three staple crops

The simulation results of the spatial pattern of the three important crops in the study area were shown in Fig. 2-A. Maize occupied the largest area of the land allocated for the three crops, especially in the plains. The three provinces in Northeast China are known as the 'Golden Maize Belt'. The Songnen Plain has climate and soil conditions that are optimal for maize growth. Thus, the simulation result was consistent with the actual situation. In addition, the purchasing price of maize has been raised from 1.2 CNY kg^{-1} in 2000 to approximately 2 CNY kg^{-1} in 2008, which strongly influenced farmers to grow maize. The acreage of maize expanded enormously from 5.42 million ha in 2000 to 8.4 million ha in 2008, and the total yield of maize increased from 23.35 to 50.94 million t. In the three provinces, the acreage and yield of maize all increased, especially in Heilongjiang Province, where the acreage increased more than one time since the acreage devoted to wheat was sowed with maize besides reclamation arable lands in the Sanjiang Plain. From Fig. 2-A, a distinct northern boundary can be observed between the Lesser Khingan Mountain and Songnen Plain based on the simulation results using the EPIC model. This phenomenon indirectly reflected the effects of latitude and temperature on maize growth.

The spatial distribution of rice was generally close to the river systems and was well represented by using $Coefficient_{rice}$. Due to its high quality, the rice produced from the three northeastern provinces has been popular in China's domestic agricultural product market. Thus, the large-scale export of rice greatly stimulated the cultivation of rice in the region. In addition, rice is the staple food of the Chinese people, and the protective purchasing price for rice generated because of the government's procurement guarantees a level of profit and offers significant incentives to local farmers to grow rice crops. The acreage of rice in the region in 2000 was 2.68 million ha, which increased to 3.7 million ha in 2008; in addition, the total production increased from 17.94 million t in 2000 to 26.02 million t in 2008.

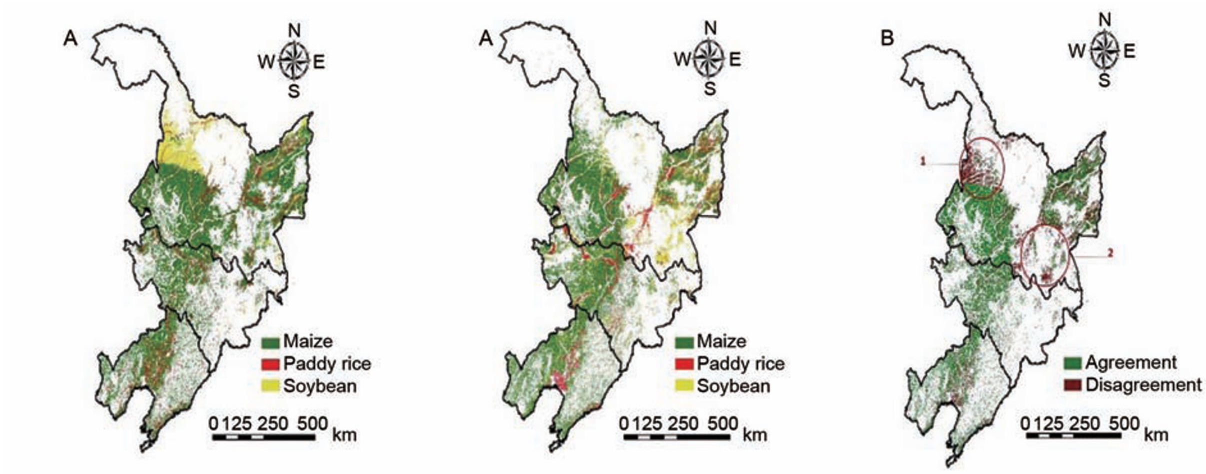

Fig. 2 Simulation and validation maps of the cropping patterns. A, simulated cropping pattern map. B, validation map. C, comparison map between the validation and simulation.

In summary, the three provinces all showed increases in rice acreage and production, with that of Heilongjiang Province increasing by nearly 50%.

The distribution of soybean (yellow areas in Fig. 2-A) was generally in the top of the Sanjiang Plain, with the soybean mainly distributed in Heilongjiang Province, which is consistent with the actual situation. In the period from the 1980s to approximately 2008, soybean has been an important crop in the Songnen and Liaohe Plains, and its acreage increased from 3.7 million ha in 2000 to approximately 4.7 million ha in 2008. However, due to low yield of local wild soybean, lacking protective purchasing price, and low-priced imported soybean impact, soybean crops have gradually been replaced by maize and rice in these important crop areas in recent years.

3.2. Validation of simulated cropping pattern

Fig. 2-B is the validation reference map used to verify the simulated result. A comparison of the validation map and simulation map showed that the overall accuracy of the simulated spatial pattern of the three crops for the study area was 78.62%. And the accuracy was an optimized result from repeated simulations including adjusting parameters of EPIC model and eq. (1). The simulation results in the plains were much better than the results in the transition zone regions (red circles 1 and 2 in Fig. 2-C), and the 21.38% error was mainly distributed in the transition zone regions between the Lesser Khingan Mountain and Songnen Plain and between the southern Sanjiang Plain and Changbaishan Mountain. In the red circle 1 of Fig. 2-C, the soybean crops were shown in the simulation, although this area was actually occupied by maize. And in the red circle 2, maize was shown in the map, although the area was actually soybean and rice. These results indicated that topography had an important impact on the accuracy of the simulation. In addition, there was no northern boundary of the maize planting region in reality, indicating that the simulated boundary by the EPIC model must be adjusted; however, the result was not caused by modeling mistakes but from the extension of maize planting to the north, which was related to the cultivation of new maize varieties that are more hardy and drought resistant. This scientific achievement could not be reflected in the EPIC model, which will be addressed in future studies.

Among the provinces, the accuracy varied significantly. The accuracy for Jilin Province (82.45%) were the highest, Liaoning Province (79.22%) in the middle, and Heilongjiang Province had the lowest accuracy (76.98%). Compared with the cropping system of Heilongjiang and Liaoning provinces, that of Jilin Province was relatively simple, with maize occupying most of the areas contributing to the Golden Maize Belt. The arable land in Jilin Province had a flat topography, which produced a high simulation accuracy. In Liaoning Province, the planting structure was slightly complicated, with rice and maize fields intermingling and fields occurring close to hills or mountains, which produced a poorer simulation accuracy. In addition, due to the accuracy problems of the vector map for water systems, the partial rice planting area affected the overall simulation accuracy. In Heilongjiang Province, the situation was much more complex, and the following conditions caused the poor simulation accuracy: all three crops were planted over large acreages, the two cultivation areas close to mountains (red circles 1 and 2 in Fig. 2-C) had complicated topography. Plain areas only constituted a small portion of the acreage.

The simulation accuracy varied remarkably among the crops. Among the three crops, the simulation accuracy of maize was the highest (81.14%), followed by that of soybean

(76.37%) and rice (75.33%). Because maize was planted in contiguous areas and located mainly in plains, the required parameters were simple, especially the field management parameters, which were easy to obtain and led to good simulation results. However, the field management parameters for rice were much more complex. The intensive regional water system was not easily represented in the vector map. All of these characteristics led to poor simulation results for rice. The simulation accuracy of soybean was between that of maize and rice.

4. Discussion

4.1. Outbreak of this method in related field

In this study, an FCS model was established and linked to the EPIC model to perform a spatialized simulation of farmer crop selections. The result demonstrated simulated spatial cropping patterns for rice, maize and soybean in the study area. This method was meaningful for simulation at a regional scale. The method employed in this study is different from methods that have been adapted by previous studies as follows: (1) spatial scale. Previous studies have employed spatial scales at the village or town levels, whereas in this study, the scale was at the regional level, which indicated that the model could be used in future studies at even larger scales; (2) Berry *et al*. (2002) and Overmars *et al*. (2007) utilized macro-factors from experts' experiences that were often far from reality, whereas the FCS model adopted in this study acquired the most direct factors related to the farmers' decision-making process through questionnaires and interviews; (3) Berger (2002) and Schreinemachers and Berger (2011) grouped farmers into different classifications, whereas in this study, the farmers within a region were considered as a whole. The authors believe that, at a large scale, it is key to explore generalized characteristics of farmers when establishing model; (4) Parker *et al*. (2003) and Batty (2005) have linked FCS models to cellular automata models, whereas in this study, the FCS model was linked to a crop growth model that contains spatial and geographical information, which allowed for considering factors of climate, soil and field management, and precisely simulating yield per unit area. Thus, the crop growth model played an important role in improving the overall simulation accuracy.

4.2. Effect of spatial scales on accuracy

Currently, similar studies at a global and continental level usually set their spatial grid to 10 km×10 km (Liu *et al*. 2011). However, at county and town levels in China, this grid is usually set at 100 m×100 m or even smaller. The grid set in this study was between the large scale and small scale and corresponded to the national level (1 km×1 km) (Ran *et al*. 2009; Liu *et al*. 2010). Future research and improved image quality (spatial resolution, spectral resolution, time resolution and map extent) should improve and increase the simulation accuracy of spatial pattern of crops to grids of 100 m×100 m or even to grids of 10 m×10 m (Chen Y *et al*. 2010).

4.3. Application scope of FCS model

Establishing a universal model at large spatial scales was considered difficult since the socio-economic conditions, agricultural policies, land systems, farmers' perspectives and perceptions, and cropping systems vary greatly among countries and even inside a country. Thus, it is important to establish the model according to local conditions. The methodology of applying shared characteristics of farmers at a regional scale and considering the farmers as a whole must also be applied according to local conditions. In addition, threshold issues must be considered; for example, the uniformity found in the farmers of the three northeastern provinces is not usually popular in other regions of China. What level uniformity and generalization of the farmers as a whole could reach for facilitating establishment of model at a certain spatial scale is very important for future relevant study. From our point of view, in order to ensure simulation accuracy, it was better to still use interviewing data with farmers if FCS model is applied to other places. Of course, input of statistical data for FCS model is another attempt orientation, but it needs accuracy validation.

4.4. Uncertainty of method

As for the consistency of the data and complexity of the model in the study, there must exist uncertainty in the model and data. Firstly, FCS model operated well in the study, however northeast China is a wide territory and total number of farmer household exceeds more than 10 million. If we repeat to do farmer investigations, there must be some error or difference with existing ones. The error or difference will result in uncertainty in simulation result to some extent. About the EPIC model, we applied a uniform series of parameters based on actual situation. In reality, under the condition of enough fund support, more spot-experiments could be conducted, in other words, more validations and calibrations could be available for Model Localization and crop genetic parameters. That will, no doubt improve accuracy of and avoid uncertainty of final simulation results to most extent. Nevertheless, the number and spatial location of spots should be further studied, since too much spots will lower operation efficiency. For climatic data, adopting the averaged values of a long time-series data, for instance, 30 yr, no doubt, enhanced the credibility of final simulation result.

4.5. Discussion on EPIC model

Although the EPIC model accurately simulated yield per unit area of the three staple crops, it is still a universal model that contains numerous simulation modules of different crops. In future studies, the specific crop growth model of rice, maize or soybean can be used for the future simulation of yield per unit area to further enhance the simulation accuracy. In addition, the EPIC model is a DOS-based model, so it is difficult to link EPIC to other Windows-based applications that are used in remote sensing and geographic systems. Therefore, it is impossible to generate Windows-based simulation software for spatial pattern of crops. This situation will be addressed in future studies.

5. Conclusion

The method and results of linking a farmer crop selection model (FCS) with an agronomic model (EPIC) to simulate cropping pattern in Northeast China in this paper was acceptable. In the future, we will attempt to improve method by making more experiments on parameters of EPIC at more spots and making more farmer investigations in the study area.

Acknowledgements

This research was funded by the National Natural Science Foundation of China (41001049, 2011–2013) and the China Regional Arable Land Resources Changes and its Warning — A Case Study in Northeast China, Ministry of Science and Technology of China (2004DIB3J092, 2003–2008). And sincere appreciation is delivered to English Language Editing of Elsevier website for polishing this paper.

References

Barnaud C, Bousquet F, Trebuil G. 2008. Multi-agent simulations to explore rules for rural credit in a highland farming community of Northern Thailand. *Ecological Economics*, **66**, 615–627.

Batty M. 2005. *Cities and Complexity: Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals*. MIT Press, Cambridge, MA.

Berger T. 2001. Agent-based spatial models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis. *Agricultural Economics*, **25**, 245–260.

Berry B J L, Kiel L D, Elliott E. 2002. Adaptive agents, intelligence, and emergent human organization: capturing complexity through agent-based modeling. *Proceeding of the National Academy of Sciences of the United States of America*, **99**, 7187–7188.

Bryant K J, Benson V W, Kiniry J R, Williams J R, Lacewell R D. 1992. Simulating maize yield response to irrigation timings — Validation of the EPIC model. *Journal of Production Agriculture*, **5**, 237–242.

Cabelguenne M P, Debaeke A, Bouniols. 1999. EPIC phase, a version of the EPIC model simulating the effects of water and nitrogen stress on biomass and yield, taking account of developmental stages: Validation on maize, sunflower, sorghum, soybean, and winter wheat. *Agricultural Systems*, **60**, 175–196.

Chavas D R, Izaurralde R C, Thomson A M, Gao X J, 2009. Long-term climate change impacts on agricultural productivity in eastern China. *Agricultural and Forest Meteorology*, **95**, 203–215.

Chen H, Yang W G, Liang X Y, Wang T. 2010. Multi-scale modeling of land use based on the MAS from field to village: A case study for Mengcha Village of Mizhi County of Shaanxi Province. *Geographical Research*, **29**, 1519–1527. (in Chinese)

Chen Y Q, Yao Y M, He Y B, Shi S Q, Li Z B. 2010. A*ssessment on Effects of Regional Arable Land Resources Changes and Food Security Early Warning*. China Agricultural Science and Technology Press, Beijing. (in Chinese)

Fischer G, Sun L. 2001. Model based analysis of future land-use development in China. *Agriculture*, *Ecosystem & Environment*, **85**, 163–176.

Frondoni R, Mollo B, Capotorti G. 2011. A landscape analysis of land cover change in the municipality of Rome (Italy): Spatio-temporal characteristics and ecological implications of land cover transitions from 1954 to 2001. *Landscape and Urban Plan*, **100**, 117–128.

Grimm V, Revilla E, Berger U. 2005. Pattern-oriented modeling of agent-based complex systems: Lessons from ecology. *Science*, **310**, 987–991.

Huang H Q, Pan L H, Wang Q, Zhen L. 2010. An artificial society model of land use change in terms of households' behaviors: Model development and applications. *Journal of Natural Resources*, **25**, 353–367. (in Chinese)

Huang H Q, Tang H J, Wu W B, Li D D, Liu J. 2013. Remote sensing based dynamic changes analysis of crop distribution pattern — taking northeast China as an example. *Scientia Agricultura Sinica*, **46**, 2668–2676. (in Chinese)

IGBP (International Geosphere-Biosphere Program). 2001. *Global Change and the Earth System: A Planet under Pressure* (IGBP Science 4). IGBP, Stochholm.

Lambin E F, X Baulies N, Bockstael G, Fischer T, Krug R, Leemans E F, Moran R R, Rindfuss Y, Sato D, Skole B L, Turner II, Vogel C. 1999. *Land Use and Land Cover Change (LUCC) Implementation Strategy*, *IGBP Report 48 & IHDP Report10*. IGBP, Stockholm.

Li N, Gao M, Fu Y H, Ma G Q. 1994. Analysis on the characteristics of spring soybean in northeast China. *Journal of Jilin Agricultural University*, **16**, 86–88. (in Chinese)

Liu J. 2009. A GIS-based tool for modelling large-scale crop-water relations. *Environmental Modelling Software*, **69**, 115–133.

Liu J Y, Deng X Z. 2010. Progress of the research methodologies on the temporal and spatial process of LUCC. *Chinese Science Bulletin*, **55**, 1–9.

Liu J Y, Zhang Z X, Xu X L, Kuang W H, Zhou W C, Zhang S W, Li R D, Yan C Z, Yu D S, Wu S X, Nan J. 2010. Spatial patterns and driving forces of land use change in China during the early 21st century. *Journal of Geographical Science*, **20**, 483–494.

Liu Y L, Chen Z L, Wang J, Ye M W, Xu S Y. 2011. Multi-scale coupling and application of natural disaster risk analysis. In: *The 19th International Conference on Geoinformatics*. IEEE, Shanghai, China. pp. 1–5.

Manson S M. 2005. Agent-based modeling and genetic programming for modeling land change in the southern Yucatan Peninsula Region of Mexico. *Agricultural Ecosystem & Environment*, **111**, 47–62.

Matthews R. 2006. The People and Landscape Model (PALM): Towards full integration of human decision-making and biophysical simulation models. *Ecological Modelling*, **194**, 329–343.

National Bureau of Statistics of the People's Republic of China. 1991–2010. *China Statistical Yearbooks*. China Statistics Press, Beijing. (in Chinese)

Niu X Z, William E, Cynthia J H, Allyson J, Linda M. 2009. Reliability and input-data induced uncertainty of the EPIC model to estimate climate change impact on sorghum yields in the U.S. Great Plains. *Agriculture*, *Ecosystem & Environment*, **129**, 268–276.

Overmars K P, Verburg P H, Veldkamp T A. 2007. Comparison of a deductive and an inductive approach to specify land suitability in a spatially explicit land use model. *Land Use Policy*, **24**, 584–599.

Parker D C, Manson S M, Janssen M A, Hoffmann M J, Deadman P. 2003. Multi-agent systems for the simulation of land-use and land-cover change: A review. *Annual Association of American Geography*, **93**, 314–337.

Priya S, Shibasaki R. 2001. National spatial crop yield simulation using GIS-based crop production model. *Ecological Modelling*, **136**, 113–129.

Ran Y H, Li X, Lu L. 2009. China land cover classification at 1 km spatial resolution based on a multi-source data fusion approach. *Advances in Earth Science*, **24**, 192–203. (in Chinese)

Saeed A K, Barlas Y, Yemgun O. 2002. Long term sustainability in an agriculture development project: A system dynamics approach. *Journal of Environmental Management*, **64**, 247–260.

Schreinemachers P, Berger T. 2011. An agent-based simulation model of human-environment interactions in agricultural systems. *Environmental Modelling and Software*, **26**, 845–859.

Tang H J, Chen Y Q, Qiu J J, Chen Z X. 2004. *Land Use and Land Cover in China*. China Agriculture Science and Technology Press, Beijing. (in Chinese)

Tang H J, Wu W B, Yang P, Chen Y Q, Verburg P H. 2009. Recent progresses of land use and land cover change (LUCC) models. *Acta Geographica Sinica*, **64**, 456–468. (in Chinese)

Turner II B L, Skole D, Sanderson S, Fischer G, Fresco L O, Leemans R. 1995. *Land Use and Land Cover Change Science/Research Plan, IGBP Report 35& IHDP Report 7*. IGBP, Stockholm.

Van Der Velde M, Wriedt G, Bouraoui F. 2010. Estimating irrigation use and effects on maize yield during the 2003 heatwave in France. *Agriculture*, *Ecosystem & Environment*, **1**, 141–147.

Verburg P H. 2006. Simulating feedback in land use and land cover change models. *Landscape Ecology*, **21**, 1171–1183.

Verburg P H, Overmars K P. 2009. Combining top-down and bottom-up dynamics in land use modeling: Exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. *Landscape Ecology*, **24**, 1167–1181.

Verburg P H, Schot P P, Dijst M J, Veldkamp A. 2004. Land use change modeling: Current practice and research priorities. *GeoJournal*, **61**, 309–324.

Wang Z Q, Fang W H, He F, Xu H. 2008. Effect of climate change on wheat yield in northern China: A research based on EPIC model. *Journal of Natural Disaster*, **17**, 109–114. (in Chinese)

Williams J R. Arnold J G. 2006. *History of Model Development at Temple*. Texas A&M University Press, College Station City, USA.

Williams J R, Jones C A, Dyke P T. 1984. A modeling approach to determining the relationship between erosion and soil productivity. *Transactions of the Asea*, **27**, 129–144.

Wu J S, Feng Z, Gao Y, Huang X L, Liu H M, Huang L. 2012. Recent progress on the application and improvement of the CLUE-S Model. *Progress of Geography*, **31**, 3–10. (in Chinese)

Wu W B, Shibasaki R, Yang P, Tan G X, Matsumura K, Sugimoto K. 2007. Global-scale modelling of future changes in sown areas of major crops. *Ecological Modelling*, **27**, 2137–2154.

Xie Y C, Yu M, Tian G J. 2005. Socio-economic driving forces of arable land conversion: A case study of Wuxian City, China. *Global Environmental Change*, **15**, 238–252.

Yin P H, Fang X Q, Tian Q. 2006. Distribution and regional differences of the main output regions in grain production in China in the early 21st century. *Acta Geographica Sinica*, **61**, 190–198.

Yu Q Y, Wu W B, Tang H J, Yang P, Li Z G, Xia T, Liu Z H, Zhou Q B. 2013. An agent-based model for simulating crop pattern dynamics at a regional scale: Model framework. *Scientia Agricultura Sinica*, **46**, 3266–3276. (in Chinese)

(Managing editor WANG Ning)